

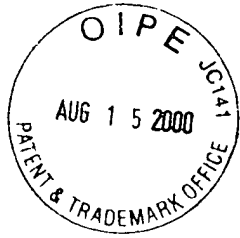


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Specification and Drawings, as originally filed, with Application for Patent Serial No:  
**2,223,225**, on November 28, 1997, by **CANADIAN RED CROSS SOCIETY**, assignee of  
Alan H. Lazarus, Andrew R. Crow and John Freedman, for "Method for Inhibiting in Vivo  
Immune Response".

  
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**ABSTRACT OF THE INVENTION**

The invention relates to a method for inhibiting *in vivo* immune response and to the use of a soluble recombinant human CD40L or a sequence within said soluble recombinant human CD40L containing the active binding site with CD40 for inhibiting an immune response. The invention also relates to a mouse model of human alloimmunization for testing *in vivo* effects of an immunotherapy or inhibition of a human antibody response.

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**METHOD FOR INHIBITING *IN VIVO* IMMUNE RESPONSE****BACKGROUND OF THE INVENTION****(a) Field of the Invention**

5           The invention relates to a method for inhibiting *in vivo* immune response and to the use of a soluble recombinant human CD40L or a sequence within said soluble recombinant human CD40L containing the active binding site with CD40 for inhibiting an immune  
10 response. The invention also relates to a mouse model of human alloimmunization for testing *in vivo* effects of an immunotherapy or inhibition of a human antibody response.

**15 (b) Description of Prior Art**

          Platelet alloimmunization occurs as a result of exposure to "foreign" antigens present in pooled random donor platelet concentrates. A consequence of platelet alloimmunization is the development of a state of  
20 refractoriness to subsequent random donor platelet transfusion. Up to 50% of patients with acute leukemia, almost 100% of those with aplastic anemia and 10% of patients with solid tumors, develop platelet alloantibodies. The alloantibodies are most often  
25 directed against HLA Class I antigens, although in 10-20% of cases they are directed against platelet-specific antigens such as Pl<sup>A</sup>, Bak, Pen. Effective platelet support for such patients is dependent upon provision of compatible platelets  
30 selected by HLA matching and/or platelet crossmatching, approaches which are expensive and, in up to one-third of cases, ineffective. A multitude of clinical and experimental studies have indicated that alloimmunization depends upon (or is at least augmented  
35 by) the presence of "contaminating" MHC class II

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bearing antigen presenting cells (APC) in the transfused blood products.

Investigators have attempted to inactivate donor APC by ultraviolet radiation, or have applied  
5 leukofiltration to remove the APC from the transfused product. Most studies, including a large US-based multi-centre study (TRAP, Trial to Reduce Alloimmunization to Platelets) have indicated that the frequency of patients that become alloimmunized is  
10 decreased when leukofiltered products are used. However, it is important to note that although these studies reduced the incidence of alloimmunization by approximately 50%, many patients still become alloimmunized.

15 The major co-stimulatory molecule for B cells is the CD40 molecule. This surface membrane protein which is found on B cells as well as some other cells interacts with a molecule on activated Th cells designated as CD40 ligand (CD40L, gp39 or CD154).  
20 CD40-CD40L interaction is critical to B cell activation and differentiation. B cells stimulated with anti-CD40 antibodies undergo transmembrane signaling, cell enlargement, and LFA-1-dependent aggregation. When B cells are stimulated via an appropriate stimuli in  
25 combination with anti-CD40, these B cells can proliferate or be induced to isotype switch depending upon the first stimulus. Patients with defective CD40L function have X-linked hyper-IgM syndrome characterized in part by low levels of serum IgG, IgA, and IgE. CD40  
30 and CD40L deficient mice have numerous immune defects including the inability to class switch from IgM to IgG<sub>1</sub> and the inability to stimulate allogenic T cells in an *in vitro* mixed lymphocyte reaction (MLR). Injection of animals with anti-CD40L antibody has been  
35 shown to inhibit both a primary and secondary antibody

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response, as well as prevent the occurrence of anti-DNA antibodies and disease pathology in lupus-prone mice. Further, administration of a soluble form of CD40L to human B cell hybridomas can induce apoptosis (U.S. Patent No. 5,540,926). While the CD40 molecule on the B cell provides co-stimulation to that cell via interaction with a Th cell expressing the CD40L, it is important to note that the T cell also becomes activated by this mutually synergistic interaction.

It would be highly desirable to be provided with a method to inhibit *in vivo* alloimmunization.

#### SUMMARY OF THE INVENTION

One aim of the present invention is to provide a method for inhibiting human anti-HLA alloimmune response.

In accordance with the present invention there is provided a use of a soluble recombinant human CD40L or a sequence within the soluble recombinant human CD40L containing the active binding site with CD40 for inhibiting an immune response. Preferably, the soluble recombinant human CD40L has the amino acid sequence 108 to 261 of the following amino acid sequence:

25	Met	Ile	Glu	Thr	Tyr	Asn	Gln	Thr	Ser	Pro	Arg	Ser	Ala	Ala	Thr	Gly	1	5	10	15
	Leu	Pro	Ile	Ser	Met	Lys	Ile	Phe	Met	Tyr	Leu	Leu	Thr	Val	Phe	Leu	20	25	30	
30	Ile	Thr	Gln	Met	Ile	Gly	Ser	Ala	Leu	Phe	Ala	Val	Tyr	Leu	His	Arg	35	40	45	
35	Arg	Leu	Asp	Lys	Ile	Glu	Asp	Glu	Arg	Asn	Leu	His	Glu	Asp	Phe	Val	50	55	60	
	Phe	Met	Lys	Thr	Ile	Gln	Arg	Cys	Asn	Thr	Gly	Glu	Arg	Ser	Leu	Ser	65	70	75	80
40	Leu	Leu	Asn	Cys	Glu	Glu	Ile	Lys	Ser	Gln	Phe	Glu	Gly	Phe	Val	Lys	85	90	95	

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Asp Ile Met Leu Asn Lys Glu Glu Thr Lys Lys Glu Asn Ser Phe Glu  
                   100                  105                  110  
 5 Met Gln Lys Gly Asp Gln Asn Pro Gln Ile Ala Ala His Val Ile Ser  
                   115                  120                  125  
 Glu Ala Ser Ser Lys Thr Thr Ser Val Leu Gln Trp Ala Glu Lys Gly  
           130                  135                  140  
 10 Tyr Tyr Thr Met Ser Asn Asn Leu Val Thr Leu Glu Asn Gly Lys Gln  
       145                  150                  155                  160  
 Leu Thr Val Lys Arg Gln Gly Leu Tyr Tyr Ile Tyr Ala Gln Val Thr  
                   165                  170                  175  
 15 Phe Cys Ser Asn Arg Glu Ala Ser Ser Gln Ala Pro Phe Ile Ala Ser  
                   180                  185                  190  
 20 Leu Cys Leu Lys Ser Pro Gly Arg Phe Glu Arg Ile Leu Leu Arg Ala  
           195                  200                  205  
 Ala Asn Thr His Ser Ser Ala Lys Pro Cys Gly Gln Gln Ser Ile His  
       210                  215                  220  
 25 Leu Gly Gly Val Phe Glu Leu Gln Pro Gly Ala Ser Val Phe Val Asn  
       225                  230                  235                  240  
 Val Thr Asp Pro Ser Gln Val Ser His Gly Thr Gly Phe Thr Ser Phe  
                   245                  250                  255  
 30 Gly Leu Leu Lys Leu  
                   260

SEQ ID NO:1

Preferably, the immune response inhibited is a  
 human anti-HLA alloimmune response. The above  
 35 identified amino acid sequence may be used to prepare a  
 medicament for immunotherapy.

In accordance with the present invention, there  
 is provided a mouse model of human alloimmunization for  
 testing *in vivo* effects of an immunotherapy or  
 40 inhibition of a human antibody response. The mouse  
 model is a severe combined immunodeficient (SCID)  
 mouse, reconstituted with human peripheral blood  
 lymphocytes (PBL) from donors.

Preferably the SCID mouse is  $\gamma$ -irradiated and  
 45 asialo-GM<sub>1</sub> treated for enhancing cellular engraftment,  
 and the donors are sensitized to HLA antigens.

Also in accordance with the present invention,  
 there is provided a method for inhibiting an *in vivo*

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immune response which comprises the step of administering to a patient a soluble recombinant human CD40L or a sequence within that soluble recombinant human CD40L containing the active binding site with  
5 CD40.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1A represents an histogram illustrating the measurements of the total IgG from Hu-PBL-SCID mice  
10 on day 18 post-engraftment by ELISA;

Fig. 1B represents a plot chart illustrating the measurements of human alloantibody from Hu-PBL-SCID mice by flow cytometry;

Figs. 2A to 2F illustrate mean  $\pm$  SEM  
15 concentrations of human IgG and IgM in SCID mice reconstituted with PBL from donors A and B;

Figs. 3a to 3F illustrate flow cytometric analysis of alloantibody production in representative SCID mice reconstituted with PBL from a donor "A" who  
20 was previously sensitized to HLA-A2;

Figs. 4A to 4F illustrate flow cytometric analysis of alloantibody production in representative SCID mice reconstituted with PBL from a donor previously sensitized to HLA-A10; and

25 Fig. 5 illustrates a cumulative comparison of alloantibody responses by flow cytometry.

#### **DETAILED DESCRIPTION OF THE INVENTION**

The method of the present invention has been  
30 evaluated using a Hu-PBL-SCID mouse model. This mouse model, developed for the present invention, is a valuable model for testing *in vivo* effects of novel immunotherapies or inhibition of the human antibody response.

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In accordance with the method of the present invention, it is proposed that anergy induction via inhibition or inappropriate activation of the CD40-CD40L co-stimulatory cascade, is effective in inhibiting an *in vivo* immune response. It is believed that the soluble recombinant CD40L active fragment competes B cell- (or APC-) CD40 interaction with CD40L on the Th cell which disallows the Th cell to be activated to secrete cytokines (such as Th2 cytokines) which thus reduce the transfusion-induced alloimmune response.

To develop an *in vivo* experimental model of human alloimmunization that would be amenable to experimental manipulation, a model was developed, in which mice with severe combined immunodeficiency (SCID) are repopulated with human peripheral blood lymphocytes (Hu-PBL-SCID) from healthy blood donors and challenged with HLA-mismatched lymphocytes.

An *in vivo* model of human alloimmunization was evaluated using severe combined immunodeficient (SCID) mice. SCID mice were irradiated (200 cGy), and reconstituted with human peripheral blood lymphocytes (PBL) from donors sensitized to HLA antigens by prior pregnancy. The reconstituted SCID mice (Hu-PBL-SCID) were then challenged with HLA-mismatched PBL. Alloantibodies were evaluated by flow cytometry (42) and a standard two stage microlymphocytotoxicity (LCT) assay (40).

The Hu-PBL-SCID mice (N=22) that were challenged with PBL expressing the HLA antigens to which the donors had previously been sensitized, made significantly increased levels of both IgM and IgG alloantibodies as compared to unchallenged mice. Responses were measurable by 1 week post-reconstitution and challenge. Prior treatment of SCID mice with anti-



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asialo-GM<sub>1</sub>, which depletes murine NK cells and macrophages, further increased the alloantibody response of challenged mice. The human alloantibodies generated were specific for the challenge HLA antigens as assessed by LCT.

Hu-PBL-SCID mice were divided into 4 groups.

Group 1 consists of mice reconstituted with PBL from donor A (as described herein except that  $10^7$  PBL were used to reconstitute the mice). These animals were bled twice weekly (18 KDa CD40L-untreated and HLA-unchallenged negative control group).

Group 2 consists of mice similar to the ones of Group 1, except that the mice were injected with 200 µg of 18 KDa CD40L via the intraperitoneal route on the day of reconstitution (18 KDa CD40L-treated and HLA-unchallenged negative control group).

Group 3 consists of mice similar to the ones of Group 1, except that the mice also received twice weekly challenges with HLA-mismatched lymphocytes (18KDa CD40L-untreated and HLA-challenged positive control group).

Group 4 consists of mice similar to the ones of Group 1, except that the mice were injected with 200 µg of 18 KDa CD40L via the intraperitoneal route on the day of reconstitution and also received twice weekly challenges with HLA-mismatched lymphocytes (18 KDa CD40L-treated and HLA-challenged experimental group).

All mice were examined for total human IgG levels as a measure of the success of functional cellular engraftment as well as to determine if the recombinant soluble 18KDa CD40L protein product inhibits or affects B cell IgG production. Fig. 1A shows that the total level of human IgG as measured after 18 days of human PBL engraftment is not statistically different in any of the groups. For the

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purposes of this disclosure, this indicates that the soluble CD40L therapeutic does not adversely affect either cellular engraftment nor does it inhibit the ability of human B cells to produce immunoglobulin. It is therefore unlikely that the CD40L therapeutic induces B cell apoptosis or non-specific B cell anergy when administered *in vivo*. The numbers under each bar indicate the group number corresponding to those of Fig. 1B. Next, in Fig. 1B, the ability of each group of mice to make alloantibody was examined. Groups 1 and 2 did not make significant levels of alloantibody (i.e. no anti-HLA antibody), as expected. Group 3 made enhanced levels of alloantibody, as expected. Group 4 which received a single dose of the soluble 18 KDa CD40L therapeutic made significantly less alloantibody than did group 3.

Administration of a single 200 µg inoculation of soluble recombinant 18 KDa CD40L active component was able to significantly decrease the human alloimmune antibody response to challenge with HLA-mismatched blood cells in a humanized SCID model system. This work therefore shows that *in vivo* administration of a single dose of soluble recombinant CD40L active component can inhibit a specific antibody response.

#### **PREPARATION OF A HU-PBL-SCID MOUSE MODEL**

##### **SCID Mice**

C.B.17 SCID virgin female mice (6-8 weeks of age) were obtained from the Hospital for Sick Children, Toronto, Ontario and were housed under gnotobiotic conditions in the St. Michael's Hospital research vivarium. Blood from the tail vein (300 µl) was collected into untreated microvette tubes (Sarstedt, Montreal, Quebec) and the serum was separated after incubation for 2 h at 22°C. Serum levels of endogenous murine IgG were determined by ELISA and animals with a serum murine immunoglobulin concentration exceeding 10

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µg/ml ("leaky" phenotype) were excluded from the study. Commencing 1 week post-reconstitution, mice were bled twice weekly for 5 weeks, and weekly thereafter until day 70 post reconstitution.

#### 5 Reconstituting PBL Donors

Female blood donors with a history of prior pregnancy were screened for evidence of circulating HLA class I alloantibodies. With informed consent, blood samples were obtained at the time of whole blood or  
10 platelet apheresis donations and were tested using a standard NIH microlymphocytotoxicity test against a panel of 30 HLA-typed lymphocytes (40). Donor "A" was blood group O, HLA A1, A3, B7 and B37 positive and had low levels of circulating anti-HLA-A2 and anti-HLA-B5  
15 alloantibodies. Donor "B" was group A, HLA A1, A2, B7 and B8 positive and had low levels of circulating anti-HLA-A10 and anti-B5, -B12 and -B17 alloantibodies.

#### Reconstitution

All SCID mice were exposed to 200 cGy of  
20 irradiation prior to reconstitution to enhance cellular engraftment. To deplete NK cells, some SCID mice were injected with 20 µl of anti-asialoGM<sub>1</sub> antisera (Wako Pure Chemical Industries LTD, Dallas, TX) 1 day prior to reconstitution. One unit of whole blood was  
25 collected into standard collection bags containing CP2D (Citrate Phosphate Double Dextrose); following centrifugation at 4550 xg for 3.2 min and removal of the supernatant plasma, buffy coats were transferred into a satellite bag. To obtain human PBL, the buffy  
30 coat was layered onto a 1.077 g/L Percoll (Pharmacia LKB, Baie d'Urfe, Quebec) gradient and separated by centrifugation (1200 x g for 30 min at 22°C). The PBL were washed three times with phosphate-buffered saline, pH 7.4 (PBS), adjusted to a concentration of  $8 \times 10^7$ /ml  
35 in 80% FCS in RPMI-1640, and 0.5 ml injected into the

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peritoneal cavity of recipient SCID mice using a 27 gauge needle.

#### **SCID Mice Challenge**

Challenge leukocytes were obtained from  
5 heparinized blood and isolated by Percoll density centrifugation as described above. Mice reconstituted with donor "A" cells were challenged with human PBL from HLA-A2 antigen positive blood donors and those reconstituted with donor "B" cells were challenged with  
10 human PBL from HLA-A10 antigen positive blood donors. A large number of different donors were used for each challenge; all expressed the pertinent challenge antigen, but expressed a variety of other antigens as well. In a separate experiment, Hu-PBL-SCID mice  
15 reconstituted with cells from donor "A" were challenged with cells from 4 individuals expressing only HLA A2, and B5 as antigens foreign to donor "A".

All challenge cells were  $\gamma$ -irradiated with 2500 cGy prior to administration to prevent engraftment in  
20 recipient mice. The first challenge consisted of  $2 \times 10^7$  PBL/mouse and subsequent immunizations were with  $10^7$  PBL/mouse. Immunizations with pooled  $\gamma$ -irradiated PBL (in 0.5 ml of 80% fetal calf serum in RPMI-1640) were performed twice weekly for 3 weeks starting on the day  
25 of reconstitution.

#### **Detection of Mouse or Human Immunoglobulin**

ELISA plates were coated with of 1.25  $\mu\text{g/ml}$  of either goat antimouse or antihuman IgG+IgM (50  $\mu\text{l/well}$ ; Caltag-Cedarlane Laboratories, Hornby, Ont.) in 50 mM  
30 carbonate/bicarbonate buffer, pH 9.6, for 18 h at 4°C. The plates were then washed three times with washing buffer (0.05% Tween 20/PBS), blocked with 0.2% Tween 20/PBS (200  $\mu\text{l/well}$ ) for 2 h at 37°C, and again washed three times with washing buffer. Sera from the mice  
35 were serially diluted in PBS, added to the plates (25

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µl/well), and incubated for 2 h at 22°C. Serially diluted normal mouse or human serum and purified mouse or human IgG were used as controls and standards. The plates were washed three times in washing buffer and 25 µl of alkaline phosphatase-conjugated F(ab')<sub>2</sub> goat antimouse or antihuman IgG or IgM (Cedarlane Laboratories) was added. After incubation at 22°C for 2 h, the plates were washed four times and 100 µl of substrate solution (5 mM p-Nitrophenyl phosphate; BioRad Laboratories, Mississauga, Ontario) was added and absorbance was measured at 405nm. The concentration of IgG and IgM was calculated based upon a standard curve.

#### Alloantibody Detection

Alloantibodies were detected by flow cytometry as previously described (42) or by a microlymphocytotoxicity test (LCT) (40) using HLA typed target cells. For flow cytometric analysis, SCID sera were diluted 1:10 and incubated with  $2 \times 10^5$  fresh HLA typed antigen positive lymphocytes in a volume of 20 µl for 1 h at 22°C. The cells were then washed twice and incubated at 22°C for 1 h in 100 µl each, of 1 µg/ml of affinity-purified fluorescein isothiocyanate (FITC)-labeled F(ab')<sub>2</sub> antihuman IgG, Fc -specific antibody and 0.5 µg/ml of affinity-purified phycoerythrin (PE)-labeled F(ab')<sub>2</sub> antihuman IgM, µ specific antibody (Tago; Biosource, Camarillo, CA). The cells were then washed twice and fixed in 1% paraformaldehyde in PBS. Cells were analyzed by flow cytometry as described previously (42). Background staining was assessed by comparison with a serum obtained from each animal prior to any manipulation. Antibody specificity for HLA antigens was confirmed using neat sera in the standard two-stage complement-dependent microlymphocytotoxicity assay using a typed panel of lymphocytes from 30 donors

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(40); a positive result was defined as > 20% lysis of target cells, unless otherwise stated.

#### **IgG Depletion**

Sera from NK-depleted challenged Hu-PBL-SCID mice were pooled and depleted of IgG by affinity chromatography. A saturating quantity of purified goat anti-human IgG, Fc-specific antibody (Atlantic Antibodies, Scarborough ME) was coupled to CNBr-activated sepharose™ 4B media according to the manufacturers directions (Pharmacia Biotech, Baie d'Urfé, PQ). The beads were blocked with excess glycine and extensively washed. Fifty (50) µl of mouse sera was added to 100 µl of packed anti-IgG coated beads with constant mixing for 1 hour at 25°C followed by removal of the supernatant fluid. This IgG-depletion was verified to reduce the IgG content of the pooled sera from 3.2 mg/ml IgG to 20 µg/ml by ELISA. This IgG-depleted sera (referred to as "pooled IgM" in Table 1 below) was then added to another 100 µl of packed fresh anti-IgG coated beads with constant mixing for 1 hour and used in the LCT.

Ten (10) SCID mice were reconstituted by ip injection with  $4 \times 10^7$  PBL and were either not further manipulated or received twice weekly ip challenge with HLA-mismatched γ-irradiated lymphocytes for 3 weeks commencing on the day of reconstitution. Challenge lymphocytes were derived from between 8-12 different donors for each challenge. These mice are hereafter referred to as "challenged mice". Both challenged and unchallenged mice made human IgG and IgM immunoglobulin (Figs. 2A and 2B), indicating that the mice were successfully engrafted with human cells. Human IgG levels in unchallenged and in challenged mice reached plateau levels by 14 days post-reconstitution and showed little variation until approximately 50 days

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post-reconstitution (Figs. 2A and 2C). Human IgM levels in unchallenged and challenged mice were similar until day 32 post-reconstitution (Figs. 2B and 2D).

Total serum human IgG (Figs. 2A, 2C and 2E) and  
5 IgM (Figs. 2B, 2D and 2F) were quantitated by ELISA. SCID mice were either reconstituted and not challenged (Figs. 2A and 2B, n=4 mice), reconstituted and challenged with HLA-A2 antigen positive lymphocytes (Figs. 2C and 2D, n=7 mice) or pretreated with anti-  
10 asialoGM<sub>1</sub>, reconstituted and challenged with HLA-A2 antigen positive lymphocytes (Figs. 2E and 2F, n=14 mice).

SCID mice reconstituted with lymphocytes from donor "A" who had anti-HLA-A2 and -B5 alloantibody were  
15 either left unchallenged or challenged with HLA-A2 antigen positive cells. Sera from these mice were tested for allo-reactive IgG and IgM antibody by flow cytometry at each bleed.

Figs. 3A to 3F show reactivity of sera from a  
20 typical mouse from each experimental group against HLA-A2 target lymphocytes. The histograms represent consecutive bleeds over the time period shown by the number of weeks post reconstitution on the right Y-axis. Shorter periods shown indicate that the mice  
25 died prior to the next bleed date. Hu-PBL-SCID mice that remained unchallenged made a low level of IgG allo-reactive antibody measurable by day 7 post-reconstitution that did not further increase with time over the study period (Fig. 3A). The unchallenged Hu-  
30 PBL-SCID mice did not have allo-reactive IgM antibody detectable by flow cytometry (Fig. 3B). In contrast, as shown by the shift to the right of the histograms, representing increased alloantibody binding, challenged mice made increasing levels of both allo-reactive IgG  
35 (Fig. 2, panel C) as well as IgM (Fig. 3D). Both

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classes of allo-reactive antibody increased until week 3 (Figs. 3C and 3D), after which time the challenge protocol was stopped.

The front histogram in all Figs. 3A to 3F represents reactivity of serum taken from these mice prior to reconstitution (prebleed), and each successive histogram peak is reactivity of serum taken at the indicated time (weeks post-reconstitution) as indicated on the right y-axis. Sera (1:10 dilution) were incubated with HLA-A2 antigen positive lymphocytes followed by antihuman IgG (Figs. 3A, 3C and 3E) or antihuman IgM (Figs. 3B, 3D and 3F) fluorochrome-labelled secondary antibody. A shift of the histogram to the right represents increased alloantibody binding. Figs. 3A and 3B show findings in a SCID mouse reconstituted but not challenged, Figs. 3C and 3D in a SCID mouse reconstituted and challenged with HLA-A2 antigen positive lymphocytes, and Figs. 3E and 3F in a SCID mouse pretreated with anti-asialoGM<sub>1</sub> to deplete NK cells, reconstituted and challenged with HLA-A2 antigen positive lymphocytes.

Previous reports have suggested that Nk cells are present in SCID mice. To determine if NK-depleted mice could undergo a better alloantibody response, 14 mice were treated with anti-asialoGM<sub>1</sub> (depletes NK cells) one day prior to reconstitution and challenge. NK-depleted challenged mice made significantly more total human IgG and IgM, indicating better overall engraftment (Figs. 2E and 2F). These NK-depleted challenged mice also produced higher IgG and IgM class alloantibody reactivity (Figs. 3E and 3F). In addition, these mice attained high steady-state levels of IgG and IgM more rapidly than non-NK-depleted challenged mice (compare Figs. 3E and 3F to 3C and 3D).



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Subsequent evaluation of reducing the numbers of reconstituting PBL of donor "A" in an otherwise identical independent experiment, showed that virtually identical results were obtained with  $10^7$  reconstituting cells (i.e. 4 times less reconstituting cells gave rise to a significant and specific alloantibody response to challenge and the magnitude of alloantibody produced was again significantly increased by prior NK cell depletion).

10           The specificities of the alloantibodies produced in the anti-asialoGM<sub>1</sub>-treated challenged mice were determined by LCT and the results are shown in Table 1 (columns labelled mouse 1, mouse 2, and mouse 3).           The LCT demonstrated complement-fixing  
15           alloantibodies to HLA-A2, as well as to the A9, and A28 antigens which share and define the 2C public epitope. Alloantibodies to HLA-B5 were also detected as well as to the B17 and B21 antigens which are known to crossreact strongly with B5. The only other consistent  
20           alloantibodies detected were against A10 and B8 which were not detectable in the donors sera nor crossreact with A2 or B5.

          To determine the specificity of the IgM alloantibody, the sera from all 3 NK-depleted-  
25           challenged mice were pooled and depleted of IgG by two rounds of IgG-specific affinity chromatography. Table I shows that the "pooled IgM" class alloantibody reactive with all pertinent HLA-A antigens were observed but B5 was the only HLA-B antigen that reacted  
30           with the IgG-depleted sera.

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**Table 1**

**Summary of anti-HLA specificity by lymphocytotoxicity testing against a 30 cell panel of sera from NK-depleted challenged mice reconstituted with PBL from donor A\***

5

HLA antigen	pan-HLA challenged				HLA-A2 and B5 challenged			
	Mouse 1	Mouse 2	Mouse 3	Pooled IgM	Mouse 4	Mouse 5	Mouse 6	Mouse 7
A1	+	-	-	-	-	-	-	-
A2	+	+	+	+	+	+	+	+
A3	-	-	-	-	-	-	-	-
A9	+	+	+	+	+	+	-	+
A10	+	+	+	w	-	-	-	-
A11	?	+	?		-	-	-	-
A28	+	+	+	+	+	+	+	+
A30	-	-	-		-	-	-	-
A31	-	-	-	-	-	-	-	-
A34	-	-	-		-	-	-	-
B5	+	+	+	+	+	+	+	+
B7	-	-	-	-	-	-	-	-
B8	?	+	+	-	-	-	-	-
B13	-	-	-		-	-	-	-
B14	-	-	-		-	-	-	-
B16	-	-	-	-	-	-	-	-
B17	+	+	+	-				
B21	+	+	+	-				
B22	-	?	-					
B27	-	-	-		-	-	-	-
B37	-	-	-		-	-	-	-
B40	-	-	-					
B42	-	-	-					
B44	-	-	-		-	-	-	-
B75	-	-	-	-	-	-	-	-

\* The HLA type of donor "A" was HLA-A1, A3, B7, B37; serum from this donor was also assessed by LCT at the time of engraftment and alloantibody reactive with the A2 and B5 antigens only could be detected.

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† A negative (-) sign denotes no reactivity with that HLA antigen; a positive (+) sign denotes that sera from that mouse reacted with panel cells expressing the corresponding HLA antigen; ? indicates that reactivity with that HLA antigen could not be verified, w designates a weak response.

Hu-PBL-SCID mice were repopulated with donor "A" lymphocytes in a separate experiment and were challenged with cells expressing HLA-A2 and B5 as the only HLA antigens foreign to donor "A". These challenged mice made alloantibody against HLA typed panel cells expressing A2, A9, A28, and B5 but not against those expressing A10 or B8 antigens (Table 1, see columns labelled mouse 4 through mouse 7).

PBL from a blood donor with low levels of serum alloantibody to HLA-A10, B5, B12 and B17 (donor "B") were also used to reconstitute mice. Mice were divided into unchallenged, HLA-A10 challenged, and NK-depleted and HLA-A10 challenged using essentially the same protocol as described for donor "A". Sera (1:10 dilution) from unchallenged, challenged, and NK-depleted challenged Hu-PBL-SCID mice were tested for allo-reactive antibody by flow cytometry against HLA-A10 antigen positive target lymphocytes. Unchallenged donor "B" mice made marginal levels of human IgG and no IgM class alloantibody as assessed by reactivity with HLA-A10 target cells (Figs. 4A and 4B). However, antigenic challenge of these mice did provoke an allo-response involving IgG but not IgM class antibody (Figs. 4C and 4D). NK-depleted challenged mice again made a stronger alloantibody response (Figs. 4E and 4F) than non-NK-depleted challenged mice and this "optimization" of the SCID milieu permitted measurable IgM class alloantibody. As with mice reconstituted with PBL from donor "A", the time to alloantibody detection in donor "B" was more rapid in the NK-depleted challenged mice (compare Figs. 4C and 4D to

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Figs. 4E and 4F). The sera from these mice were subjected to analysis by LCT testing. Alloantibodies were not detected in unchallenged mice but alloantibodies reactive with HLA-A10 were observed in all challenged mice and all anti-asialoGM<sub>1</sub>-treated-challenged mice.

In Figs. 4A to 4F, sera (1:10 dilution) in this case were incubated with HLA-A10 antigen positive lymphocytes followed by antihuman IgG (Figs. 4A, 4C and 4E) or antihuman IgM (Figs. 4B, 4D and 4F). Figs. 4A and 4B show findings in a SCID mouse reconstituted but not challenged, Figs. 4C and 4D in a SCID mouse reconstituted and challenged with HLA-A10 antigen positive lymphocytes, and Figs. 4E and 4F in a SCID mouse pretreated with anti-asialoGM<sub>1</sub> to deplete NK cells, reconstituted and challenged with HLA-A10 antigen positive lymphocytes. The mice represented in Figs. 4A/4B and 4E/4F died after 2½ and 3½ weeks postreconstitution, respectively.

The cumulative flow cytometric data for all donor "A" and "B" reconstituted SCID mice over 5 experiments against antigen positive cells is shown in Fig. 5. The data from the challenged group is the mean reactivity of sera from 22 mice and the unchallenged group is the mean of 13 mice. All NK-depleted challenged mice (22/22) made alloantibody that reacted with antigen positive challenge cells.

Hu-PBL-SCID mice were unchallenged (□, n=13) or challenged with leukocytes (■, n=22) and assessed for IgG class alloantibody reactivity using typed antigen positive cells. The data on the Y-axis is reported as the mean log fluorescence intensity (± SEM) for all mice.

An *in vivo* model of the secondary immune response was established in a Hu-PBL-SCID mouse model

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system using lymphocytes from previously sensitized individuals. Intraperitoneal inoculation of SCID mice with these previously sensitized human PBL resulted in engraftment of the mice and challenge with HLA-mismatched lymphocytes resulted in specific alloantibody formation in all mice. This model was used on 12 donors who were not sensitized to HLA antigens. It was found that HLA-specific antibody was never observed. Therefore this model can also be used for defining persons functionally immunized to an antigen as will be described later.

It is known that SCID mice do not contain functional B cells or T cells. The mice do however possess essentially normal NK cells which can inhibit human lymphocyte engraftment and antibody production, likely by destroying the engrafting cells. It has been shown in the present application that pretreatment with anti-asialoGM<sub>1</sub> to deplete NK cells resulted in greater IgG and IgM production and in specific alloantibody production over that seen in non-NK-depleted challenged mice. Thus, pretreatment of SCID mice with anti-asialoGM<sub>1</sub> did allow maximal alloantibody production.

The lymphocytes used for antigenic challenge of mice reconstituted with PBL from donor "A" were from individuals that were all HLA-A2 antigen positive. Each challenge consisted of lymphocytes derived from between 8-12 different individuals and a different series of individuals was used for each challenge; this was necessary to obtain sufficient PBL for immunization of all mice with the same PBL. Thus, these mice were exposed to lymphocytes from a large number of different donors possessing a wide spectrum of other HLA Class I and Class II antigens in addition to HLA-A2. The response of the mice consisted of alloantibodies to several HLA antigens in addition to A2. The phenomenon

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of "responders" is well recognized i.e. individuals who make antibody to one challenge are likely to make antibodies to challenge with new immunogenic antigens. These other antibodies could represent primary responses to HLA antigens or secondary responses of previously undetected antibodies, or alloantibodies that are cross reactive with either A2 or B5 which pre-existed in donor "A". The anti-HLA-A alloantibodies produced included anti-A2, -A9, -A10, -A11 and -A28. Since the A9 and A28 antigens are well known to cross react with A2, reactivity with these HLA-A alloantigens is not unexpected. It is however more difficult to account for anti-A10 and A11 reactivity. The anti-A10 and -A11 represent either primary responses, or a secondary response to a putative paternal HLA antigen where the antibody was not initially detectable in the serum of donor "A". Since the paternal HLA typing is unknown, it was not possible to differentiate between these possibilities, however, IgM alloantibody was not produced to the A10 and A11 antigens and therefore the alloantibodies reacting against A10 and A11 are likely an amnestic response. In the case of responses to HLA-B antigens; since donor "A" had pre-existing anti-B5, alloantibody reactive with this antigen is expected. IgM alloantibody reactive with HLA-B antigens could only be detected to B5. Donor A's HLA type was HLA A1, A3, B7 and B37 and none of the mice generated antibodies that reacted with these "self antigens" despite the strong likelihood that the pooled challenge PBL would express these antigens (A1 found in 26% of the Caucasian population, A3 in 25%, and B7 in 22%). This indicates that the mice maintained specificity for foreign antigens without generating auto-reactive antibody. In addition, the fact that challenge with A2- and B5-only expressing cells did not induce

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formation of A10 and B8 indicates that a generalized immune stimulation was not simply induced but that the allospecificity was maintained for the stimulating cells.

5 Mice reconstituted with PBL from either donor "A" or "B" made IgM as well as IgG alloantibodies. This is of interest because although IgG is well known to be produced in a secondary response from activation of memory B cell clones, IgM production is not  
10 generally considered to be produced by memory B cell clones. Antibodies of the secondary response have however been observed without class switching and experiments with adoptive primary and secondary responses have shown that memory B cells producing IgM  
15 can be observed. An alternative explanation may be that these previously sensitized donors possess memory T helper cells to HLA antigens that are able to efficiently activate "naive B cells" to secrete IgM. Coupling of secondary T cell carrier epitopes to  
20 primary haptens has been reported to generate primary immunization in Hu-PBL-SCID mice. The T cells most often found in Hu-PBL-SCID mice show the CD45<sup>RO</sup> memory phenotype and it has been reported that transfer of CD45<sup>RO</sup>, but not CD45<sup>RA</sup> (naive phenotype), T helper  
25 cells could induce purified human B cells in SCID mice to produce immunoglobulin. It is therefore possible that primary IgM-secreting B cells were activated via the memory T cell pool present in the two donors employed for reconstitution of the SCID mice.

30 It was thus demonstrated in the present application that lymphocytes from individuals previously sensitized to HLA antigens can reconstitute SCID mice and can generate reproducible IgG and IgM allo-immune responses following repeated challenge with  
35 selected "foreign" HLA antigens. The development of

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this model will allow detailed study of the mechanisms of alloimmunization and should facilitate the *in vivo* assessment of new strategies for the modulation of human alloimmunization to blood cell antigens.

5           The present invention will be more readily understood by referring to the following examples which are given to illustrate the invention rather than to limit its scope.

10

**EXAMPLE I****Immunotherapy drug screening design for alloantibody**

Scid mice as prepared in accordance with the present invention are engrafted with human PBL from pregnancy sensitized blood donors and challenged with  
15 HLA-mismatched lymphocytes in the presence or absence of any drug or therapeutic (i.e. such as an immunotherapeutic to include IVIG, anti-idiotypic antibodies, CTLA4Ig, anti-CD40 ligand antibody, anti-CD40 antibody, cyclosporine A, FK506, biologically  
20 active peptides, etc.). The HLA-specific human IgG and IgM were measured as described above.

**EXAMPLE II****Evaluation of functional immunization  
of an individual with an antigen**

25

Scid mice as prepared in accordance with the present invention are engrafted with PBL from an individual who has been vaccinated (to polio, tetanus, HIV, cancer cells or cancer antigens, etc.) or not.  
30 The Hu-PBL-SCID mice are challenged with the same antigen. The antigen-specific human IgG and IgM produced in the mice are measured. The persons exposed to a functional or protective vaccine make antigen-specific or neutralizing IgG and IgM.

35



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**EXAMPLE II****Immunotherapy drug screening design for alloantibody**

Scid mice as prepared in accordance with the present invention are engrafted with PBL from an individual who has been vaccinated as described in Example II above. The Hu-PBL-SCID mice are challenged with the same antigen in the presence or absence of any drug or therapeutic, such as described in Example I above. The antigen-specific human IgG and IgM are measured as described above.

While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modifications and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth, and as follows in the scope of the appended claims.

## SEQUENCE LISTING

## (1) GENERAL INFORMATION:

## (i) APPLICANT:

(A) NAME: The Canadian Red Cross Society  
 (B) STREET: 1800 Alta Vista  
 (C) CITY: Ottawa  
 (D) STATE: Ontario  
 (E) COUNTRY: Canada  
 (F) POSTAL CODE (ZIP): K1G 4J5  
 (G) TELEPHONE: 613-739-2408  
 (H) TELEFAX: 613-739-2426

(ii) TITLE OF INVENTION: Method for inhibiting in vivo immune response

(iii) NUMBER OF SEQUENCES: 1

## (iv) COMPUTER READABLE FORM:

(A) MEDIUM TYPE: Floppy disk  
 (B) COMPUTER: IBM PC compatible  
 (C) OPERATING SYSTEM: PC-DOS/MS-DOS  
 (D) SOFTWARE: PatentIn Release #1.0, Version #1.30 (EPO)

## (2) INFORMATION FOR SEQ ID NO: 1:

## (i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 261 amino acids  
 (B) TYPE: amino acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(iii) HYPOTHETICAL: NO

(iv) ANTI-SENSE: NO

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 1:

Met	Ile	Glu	Thr	Tyr	Asn	Gln	Thr	Ser	Pro	Arg	Ser	Ala	Ala	Thr	Gly
1				5				10						15	
Leu	Pro	Ile	Ser	Met	Lys	Ile	Phe	Met	Tyr	Leu	Leu	Thr	Val	Phe	Leu
			20					25					30		
Ile	Thr	Gln	Met	Ile	Gly	Ser	Ala	Leu	Phe	Ala	Val	Tyr	Leu	His	Arg
		35				40					45				
Arg	Leu	Asp	Lys	Ile	Glu	Asp	Glu	Arg	Asn	Leu	His	Glu	Asp	Phe	Val
		50				55					60				

[illegible]

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Use of a soluble recombinant human CD40L or a sequence within said soluble recombinant human CD40L containing the active binding site with CD40 for inhibiting an immune response.
2. The use of claim 1, wherein the soluble recombinant human CD40L has a sequence consisting in amino acids 108 to 261 of sequence set forth in SEQ ID NO:1.
3. The use of claim 2, wherein the immune response is an alloimmune response.
4. The use of claim 3, wherein the alloimmune response is a human anti-HLA alloimmune response.
5. Use of a soluble recombinant human CD40L or a sequence within said soluble recombinant human CD40L containing the active binding site with CD40 for the preparation of a medicament for immunotherapy.
6. A mouse model of human alloimmunization for testing *in vivo* effects of an immunotherapy or inhibition of a human antibody response, characterized in that the mouse model is a severe combined immunodeficient (SCID) mouse, reconstituted with human peripheral blood lymphocytes (PBL) from donors.
7. The mouse model of claim 6, wherein the SCID mouse is  $\gamma$ -irradiated and asialo-GM<sub>1</sub> treated for enhancing cellular engraftment.

8. The mouse model of claim 6, wherein the donors are sensitized to HLA antigens.

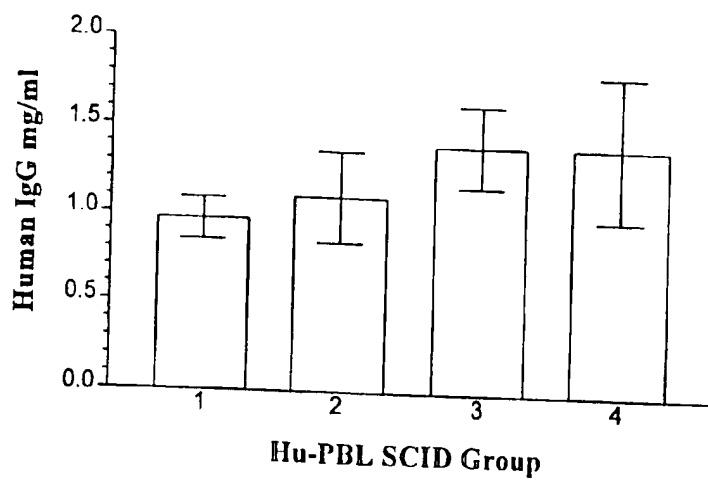


Fig. 1A

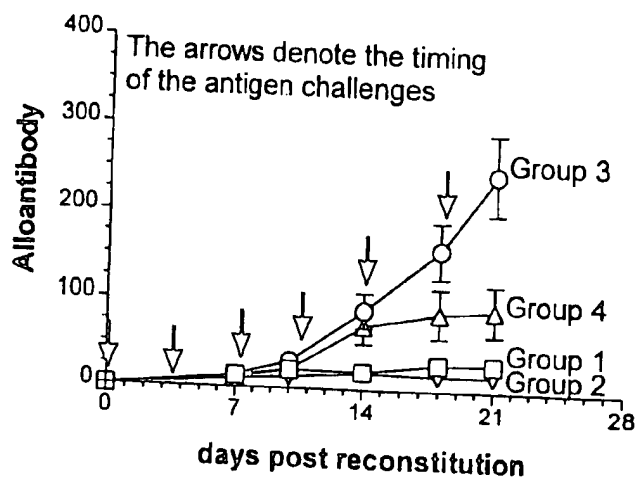


Fig. 1B

IgG

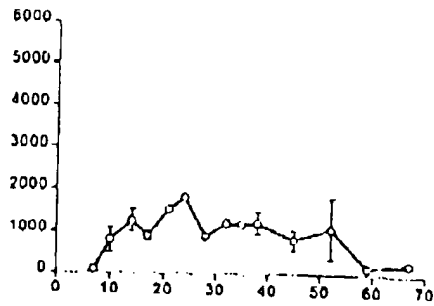


Fig. 2A

IgM



Fig. 2B

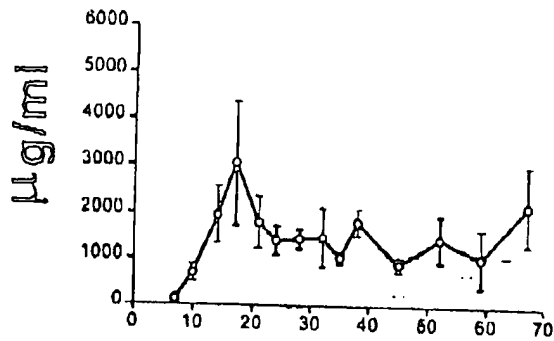


Fig. 2C

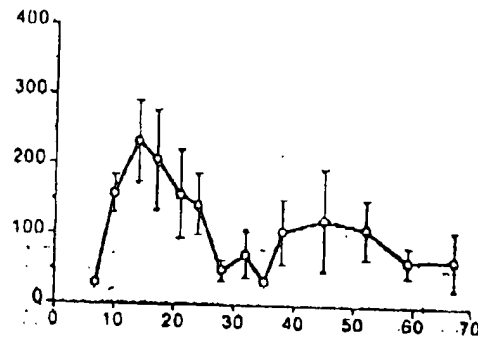


Fig. 2D

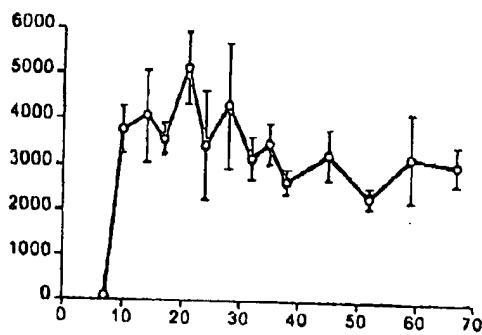


Fig. 2E

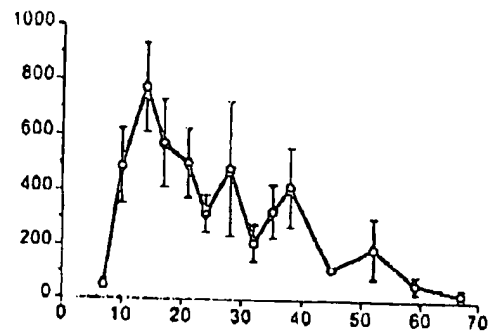


Fig. 2F

Days post reconstitution

Weeks post reconstitution

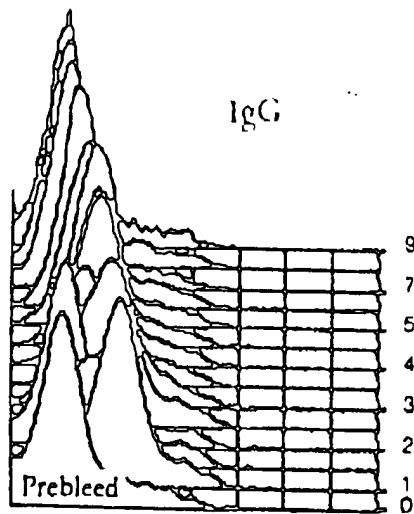


Fig. 3A

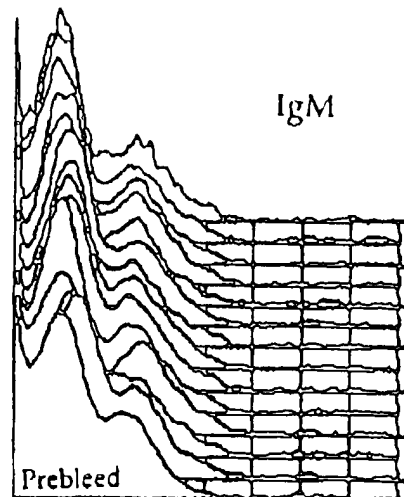


Fig. 3B

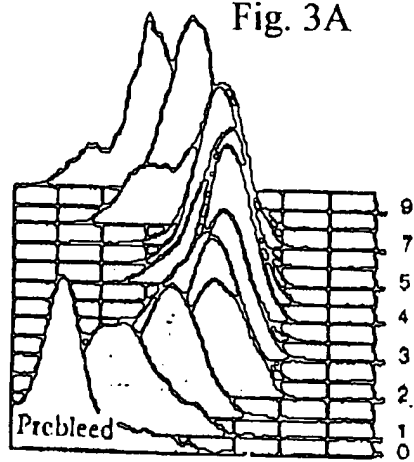


Fig. 3C

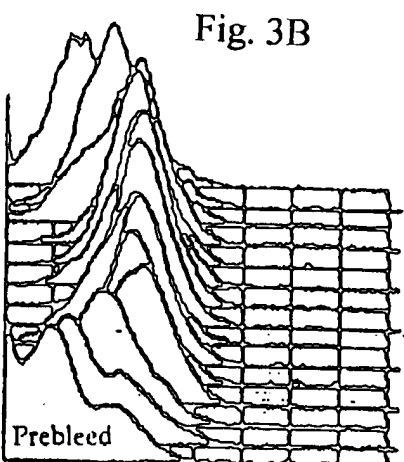


Fig. 3D

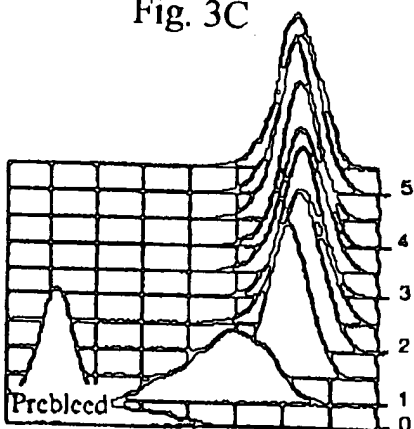


Fig. 3E

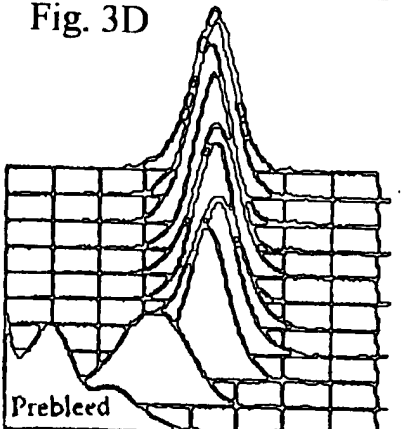
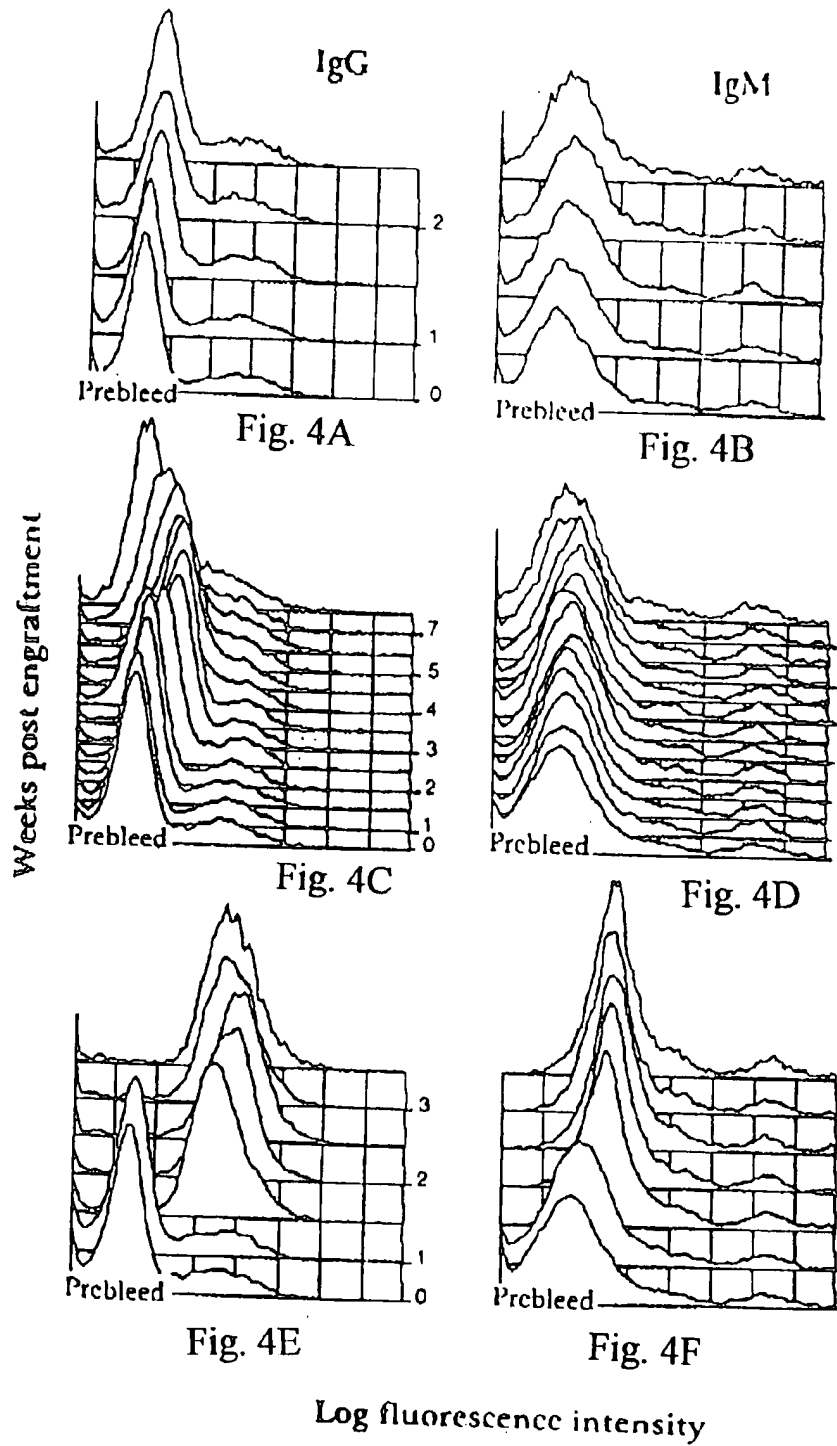


Fig. 3F

Log Fluorescence intensity





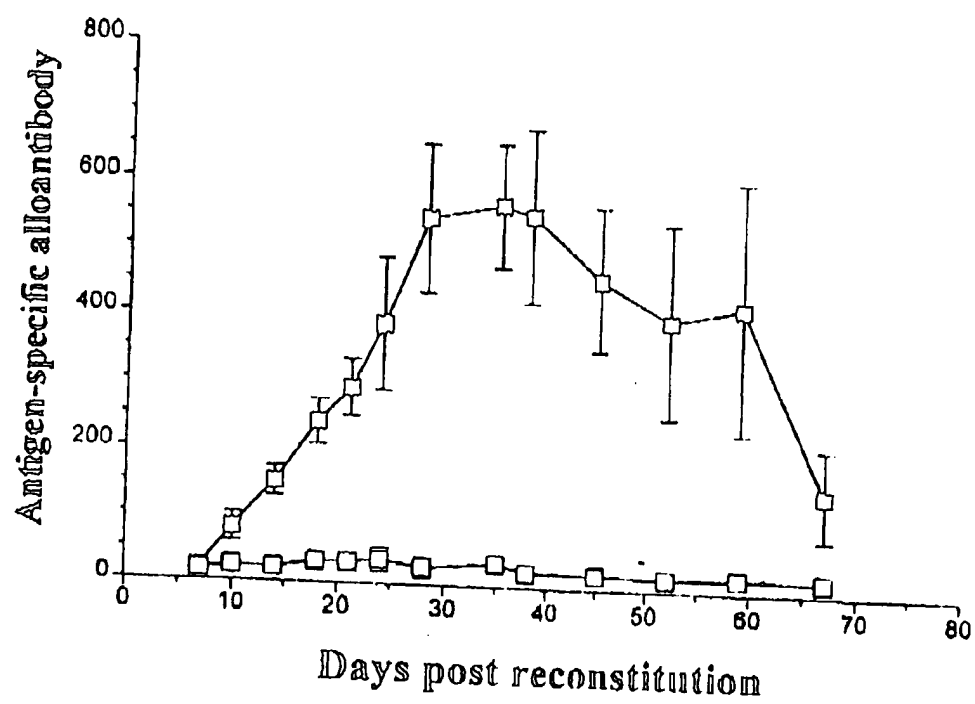


Fig. 5